Journal of Forestry Research (2010) 21(3): 379–386
DOI 10.1007/s11676-010-0085-0

ORIGINAL PAPER

Effects of improved fallow with *Sesbania sesban* on maize productivity and *Striga hermonthica* infestation in Western Kenya

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Received: 2009-09-14 Accepted: 2009-12-15

Abstract: *Striga hermonthica* is a major constraint to smallholder subsistence agriculture production in the sub-Saharan African region. Low soil fertility and overall environmental degradation has contributed to the build-up of the parasitic weed infestation. Improved cropping systems have to be introduced to address the interrelated problems of *S. hermonthica* and soil fertility decline. Thus, the effects of improved fallow with leguminous shrub *Sesbania sesban* on maize yields and levels of *S. hermonthica* infestation on farm land in the bimodal highlands of western Kenya were investigated. The experimental treatments were arranged in a phased entry, and randomized complete block scheme were six months *Sesbania* fallow, 18 months *Sesbania* fallow, six months natural fallow consisting of regrowth of natural vegetation without cultivation, 18 months natural fallow, continuous maize cropping without fertilizer application, and continuous maize cropping with P and N fertilization. Results show that *Sesbania* fallows significantly (p<0.05) increase maize yield relative to continuous unfertilized maize. *S. hermonthica* plant populations decrease in continuous maize between the first season (mean = 428 000 ± 63 000 ha^{-1}) and second season (mean=51 000 ± 15 000 ha^{-1}), presumably in response to good weed management. *S. hermonthica* seed populations in the soil decrease throughout the duration of the experiment in the continuous maize treatments. Short-duration *Sesbania* fallows can provide modest yield improvements relative to continuous unfertilized maize, but short-duration weedy fallows are ineffective. Continuous maize cultivation with good weed control may provide more effective *S. hermonthica* control than fallowing.

Foundation project: This work was supported by Swedish International Development Cooperation Agency (Sida)

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Responsible editor: Hu Yanbo

Keywords: agroforestry; crop yield; improved fallow; residual effect; root parasite; soil fertility replenishment

Introduction

The obligate root parasitic weed *Striga hermonthica* (Del.) Benth. constitutes one of the most important biotic constraints to the production of food crops for small-scale farmers in sub-Saharan Africa (Scholes and Malcolm 2008; Kiwia et al 2009). It infests and may cause severe stunting and yield losses of 30–90% (van Ast et al. 2005) in the staple food and industrial crops of the region, including cereals (e.g. sorghum, pearl millet, finger millet, maize, rice, wheat, and sugar cane), some broadleaf crops such as cowpeas, sunflower, and soybean, and various cultivars of beans. The incidence of *S. hermonthica* is known to negatively correlate with soil fertility, particularly nitrogen (N) availability (Pieterse and Verkleij 1991). Several studies have confirmed reduced *S. hermonthica* infestation and increased crop yield when high level of N was applied to the crop. In the East African highlands, despite high yield potential, continuous cropping with low levels of nutrient inputs has led to declining soil fertility and a high prevalence of related crop pests and diseases, resulting in low crop yields (Buresh et al. 1997). In Kenya, *S. hermonthica* was estimated to infest about 75 000 ha of maize crop (Hassan et al. 1995) and the rate of infestation, both in severity and spread, has been increasing over the years as depletion in soil fertility in smallholders' farms continues.

The control of *S. hermonthica* is difficult to achieve because of its high fecundity (Andrianjaka et al. 2007); also its roots grow into the crop roots and sap out all the plants' nutrients. In addition, the seed germination is asynchronous (Worsham and Egley 1990). Therefore management of *S. hermonthica* infestation needs an integrated approach including host plant resistance, cultural practices, and chemical and biological treatment (Andrianjaka et al. 2007). Improved fallow systems, which involve the use of perennial legume shrubs, are receiving increased research attention as a promising method for resource-poor farming communities (Pisanelli et al. 2008). Improved fallow requires inter-

ruption of cereal production, which may not be favorably accepted by subsistence farmers. However, it could be an attractive option as it accelerates the process of soil rehabilitation and thereby shortens the length of the fallow period. Improved fallows where nitrogen-fixing trees are planted may increase soil fertility more quickly than natural weedy fallows (Hassan et al. 1995). Further legume shrubs can be valuable sources of scarce commodities (fodder and fuelwood), and improve soil nutrient status, particularly nitrogen, through biological nitrogen fixation and nutrient recycling (Hartemink et al. 2000). Evidence suggests that perennial legume species could improve soil chemical and physical properties, creating less favorable environment for the pest (Gallagher et al. 1999). The trees and shrubs in the fallow also provide another important service to the farmer: they fill the space and impede the establishment of undesirable weeds. Many kinds of invasive and problematic weeds thrive in open, sunny conditions on vacant land, but do not spread into areas that are cooler and shadier. The plants that are part of the improved fallow create conditions that are unfavorable to most problematic weeds, making the subsequent establishment of crops easier than if the area had to be cleared of undesirable weeds.

In eastern and southern African region, smallholder maize farmers are increasingly using *Sesbania sesban* (L.) Merr. (sesbania) as a major source of N input to their N-deficient soils to increase productivity (Niang et al. 1996). It is a fast growing N_2-fixing tree with important agroforestry attributes, e.g. provision of fuelwood, fodder and high biomass for soil fertility replenishment. *Sesbania*, grown in rotation with crops has been shown to improve soil fertility and increase crop yields (Kwesiga and Coe 1994). In high rainfall areas of western Kenya, Jama et al. (1998b) found that one and a half year *Sesbania* fallows were more effective than a natural fallow in increasing maize yields.

The same pattern was found in a meta-analysis of experiments on the response of maize to fallows in sub-Saharan Africa (Sileshi et al. 2008). *Sesbania* and natural fallows compared to maize monoculture have been shown to increase the nitrogen in light fraction soil organic matter and available soil N (Maroko et al. 1998). A sizable proportion of N in *Sesbania* fallows is a net input of N to the soil-plant system through biological N_2 fixation and capture of nitrate from below the rooting depth of crops (Kwesiga and Coe 1994; Jama et al. 1998a). Some of the beneficial effects on yields of fallows may be related to a rotational effect. However, there is limited knowledge (Crookston et al. 1991) on how different duration fallows affect residual crop yields to guide economic analyses and recommendations to farmers. Thus the present study aimed at evaluating the residual effects of six- and 18 months *Sesbania* and natural fallows compared with continuous maize production on maize yields, the prevalence of *S. hermonthica* plants and soil seed bank.

Material and methods

Site description

The study site is located in Central Bunyore, Vihiga District (00°06'N, 34°34'E) at an altitude of 1,430 m a.s.l. in Western Kenya. The cropping seasons were bimodal. The long rains (LR) cropping season are from March to July and the short rains (SR) cropping season are from September to January. Based on data collected from *in situ* mini-weather station at the site, the mean (± SE) annual rainfall during the period (1994–1997) was 814 ± 32 mm for the long rain season and 740 ± 149 mm for the short rain season. The overall mean annual rainfall for the period was 1,552 ± 178 mm with large inter-annual and inter-month variability (Fig. 1). The most frequently encountered soils are Kandiudalfic Eutrudox according to FAO soils classification system. The site was previously cropped with maize. The site was chosen to be P-sufficient for maize, but degraded from continuous cropping and with a high prevalence of *S. hermonthica*.

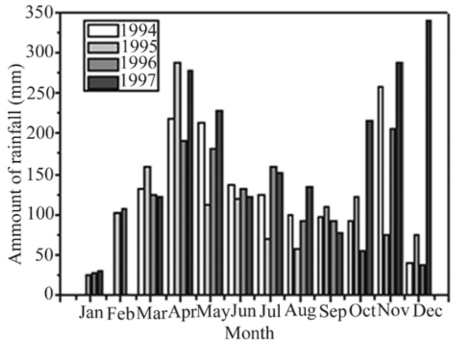

Fig. 1 Mean monthly rainfall (mm) during the study period at Ebukanga experimental site, Vihiga district, western Kenya

The agricultural system in the study area is characterized by traditional subsistence farming of mixed crop-livestock. The major crops are maize, mostly unimproved varieties and bean (*Phaseolus vulgaris* L.). Farmlands are small (mean size < 2 ha) due to high population densities and the subdivision of farms for inheritance. In spite of the small holding, short duration unmanaged fallows are common at Bunyore (Swinkels et al. 1997). For example, a survey in western Kenya showed that 52% of the farmers periodically fallow 10–50% of their total farmland at a time (Swinkels et al. 1997). The lengths of the fallow varied between one season (24% of fallowers), one year (35%) and two or more years (42%).

Experimental design

A randomized complete block design with four replicates experiment (Fig. 2) was established to examine the effect of improved fallow with leguminous shrub *Sesbania sesban* on maize yields and levels of *S. hermonthica* infestation on farm land in the bimodal highlands of western Kenya. Six treatments were applied: six months tree growth with *Sesbania* fallow (S6); 18 months tree growth with *Sesbania* fallow (S18); six months natural regrowth of vegetation fallow without cultivation (N6); 18 months natural regrowth of vegetation fallow without cultivation (N18); continuous maize cropping (M), and continuous maize cropping associated with fertilizer (60 kg P_2O_5 + 60 kg N/ha/season) application (MF). A phased entry design was applied to allow comparisons between crop yields after different

lengths of fallows within the same year (Table 1). Gross plot size was 10 m × 10 m and the net plot was 6 m × 7 m. Borders around the gross plots of 1.5 m were used to allow trenching. Border trenching was done down to 1 m below the soil surface to minimize root competition between plots. The plots were laid so as to minimize within plot variation, on the basis of variation in previous maize growth and assessment of soil characteristics.

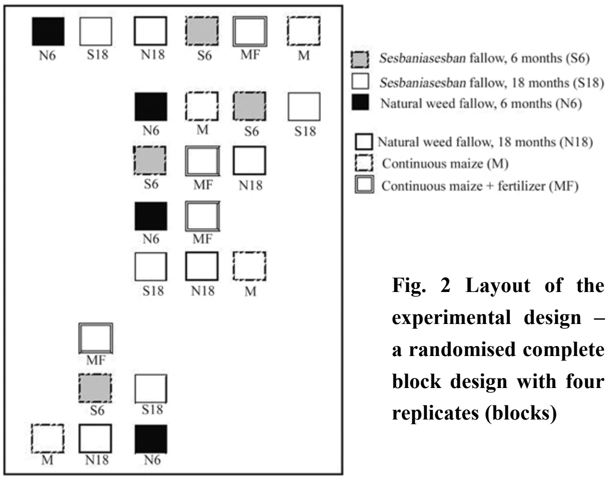

Fig. 2 Layout of the experimental design – a randomised complete block design with four replicates (blocks)

Crop and soil management

The experimental area was uniformly cropped with unfertilized maize during the growing season (short rain in 1993) preceding the start of the experiment to facilitate subdivision into blocks. At the establishment of the experiment pre-trial soil physical and chemical properties were assessed. Soil sampling was done after tillage, when soil had settled after early rain, by taking a composite of nine samples per plot at depths 0–15, 15–30, 30–50, 50–100, 100–150 and 150–200 cm. The 0–15 cm samples were taken with a core sampler of internal diameter 2.5 cm and the samples from below 15 cm were taken using a 5.28-cm diameter auger. The soil analyses were conducted by the ICRAF soil laboratory using standard methods, as reported by Shepherd and Walsh (2002). Some of the physical and chemical properties of the composite sample of the soil are presented in Table 2. Fertilizer test strips, outside the plots, (1 m^2) were laid out at the site prior to the experiment to determine maize response to fertilizer. Land preparation prior to the experiment consisted of slashing of the maize stover and weeds from the previous crop and removal of all organic residues except on the plots where natural weed fallow treatment was involved. Tillage was done using human labour to limit biomass and *S. hermonthica* seed carryover between plots.

Table 1. Summary of the experimental treatments at each growing season.

Treatments	1994		1995		1996		1997		1998
	LR	SR	LR	SR	LR	SR	LR	SR	LR
S6	M	M	MS6	S6	M	M	M	M	M
S18	MS18	S18	S18	S18	M	M	M	M	M
N6	M	M	M	N6	M	M	M	M	M
N18	M	N18	N18	N18	M	M	M	M	M
M	M	M	M	M	M	M	M	M	M
MF	MF	MF	MF	MF	MF	MF	MF	MF	MF

LR=long rains period (March-July), SR=short rains period (September-January), S6=six months tree growth with *Sesbania* fallow, S18=18 months tree growth with *Sesbania*, N6=six months natural re-growth of vegetation fallow without cultivation, N18=18 months natural re-growth of vegetation fallow without cultivation, M=continuous maize cropping, and MF=continuous maize cropping with fertilizer (60 kg P_2O_5 + 60 kg N/ha) application, MS=Maize and *Sesbania* intercropped.

Table 2. Soil properties at the start of the experiment in 1994 at Ebukanga experimental site, Vihiga district, western Kenya.

Soil depth (cm)	pH in water	Exchangeable Ca $cmol_c \cdot kg^{-1}$	Exchangeable Mg $cmol_c \cdot kg^{-1}$	Exchangeable K $cmol_c \cdot kg^{-1}$	Extractable P $mg \cdot kg^{-1}$	Total organic C %	Sand %	Silt %	Clay %
0–15	6.2	8.0	1.8	0.65	13	1.81	35	30	35
15–30	6.3	7.8	1.7	0.45	18	1.43	34	21	45
30–50	6.4	6.4	1.5	0.37	10	0.96	30	16	54
50–100	6.6	4.7	1.4	0.49	6	0.64	28	18	54
100–150	6.4	3.6	0.9	0.57	3	0.41	34	18	48

Three maize seeds (Kenya Seed Company, hybrid 511 *Zea mays* L.) were sown and thinned to one plant per hole after emergence. The maize stand density for all seasons was 53 000 plants·ha^{-1} (0.75 m × 0.25 m spacing) which is the agricultural extension service recommendation. The above-ground maize biomass and weeds were removed from the plots at each harvest. The plots were kept weed-free throughout the growing seasons by hoe and two hand weeding operations. Weeding of *S. hermonthica* was carried out as part of the regular weeding practiced by farmer. Predominant weeds were *Tephrosia holstii* Taub. *Vernonia lasiopus* O. Hoffm., and *Digitaria velutina* P. Beauv. The tree material used was the leguminous N_2-fixing species *Sesbania* Kisii, Maseno, Kenyan provenance from an ICRAF tree screening trial in Malawa, Kakamega district. The *Sesbania* fallows were established through direct sowing together with maize in the long rains of 1994 and 1995 to allow establishment and survival of the trees. After soaking seeds overnight, *Sesbania* was sown at a rate of five seeds per hole at 0.75 m × 0.25 m spacing in the middle of the maize inter-rows. The *Sesbania* was thinned to three plants per hole after emergence and to one plant per hole when 15 cm high. The *Sesbania* was inoculated at the time of sowing using compatible *Rhizobium* inoculants from Nairobi University. Maize and *Sesbania* were growing together for four months before the maize was harvested and the actual fallow period started. In the 6- and 18-month natural fallows we let the natural weed vegetation grow without interference. All the

Sesbania and natural weed fallows were harvested in January 1996 and then five successive maize crops were grown.

Plant measurements

At maturity, maize was harvested and the fresh weight of stover and cobs were recorded in the entire plot. Cobs were separated into core and grain. Subsamples of cobs and stover were taken from each plot and air-dried. At the end, maize grain yields were expressed on 15% water content. During each cropping season, *S. hermonthica* assessment was done once. Aboveground *S. hermonthica* biomass was collected within each plot from five randomly selected spots (0.75 m × 1.33 m) at the end of each cropping season. The location of these spots was chosen systematically to avoid selecting the same location in consecutive years. Weeds were harvested manually by cutting at the base and mixed together. Fresh weight of the weed mixture was taken and moisture content was determined on a subsample of 300 g oven-dried at 70°C until constant weight. Within each net plot of 6 m × 7 m, we also recorded the number of individuals of *S. hermonthica* a few weeks before the harvest. *S. hermonthica* plants were not uprooted but left to seed until maize was harvested. Further, quantification of seed bank dynamics of *S. hermonthica* was undertaken in all plots. Core samples were collected from nine spots at the centre of each plot, bulked and then placed in bags. These samples were air-dried and grounded to pass through a 2-mm sieve. From the sieved a sample of 500 g was separated to determine the *S. hermonthica* seed bank using the elutriation and column separation method (Ndung'u et al. 1993).

Statistical analysis

Yield data and *S. hermonthica* counts were subjected to analysis of variance. In the analysis counts of *S. hermonthica* plant and seed, and yield data showing heterogeneity of variance were transformed to their logarithm values before analysis to improve the normality. To account for zero values in some of the initial data on *S. hermonthica* plants log (x+1) transformation was done before doing analysis of variance. Descriptive statistics presented are of original untransformed data. ANOVA was performed separately for each parameter using the following model:

$$Y_{ij} = \mu + B_i + T_j + e_{ij}$$

where Y_{ij} is the response variable, μ is the overall mean, T_j is the effect of the treatment, B_i is the block effect and e_{ij} is the error term. Multiple comparisons were made with Tukey's test to detect differences between treatments at 5% level of significance. All statistical analyses were done using SPSS 16 software package (SPSS for Windows, Release 2007 Chicago: SPSS Inc.).

Results

Maize yield during the fallow and the rotation cycle

As a result of the fallow period there was no maize production for one season in the 6-month fallows (SR 1995) and for three seasons in the 18-month fallows (SR 1994 and 1995 and LR 1995). The total above-ground biomass of maize (cobs + stover) during the first cropping season (LR 1994) of the fallow did not differ significantly ($F_{5, 15} = 1.71$, $p = 0.193$) with respect to the treatments. The total above-ground biomass (LR 1994) was 2.10 ± 0.66 and 2.70 ± 0.40 t·ha^{-1}, respectively in the *Sesbania* fallow (S18) and the natural fallow (N18); it ranged from 2.43 ± 0.49 to 3.13 ± 0.71 t·ha^{-1} in the S6 and N6 while it was 2.73 ± 0.53 and 5.00 ± 1.34 t·ha^{-1}, respectively in the continuous cropping (M) and the continuous cropping with fertilization (MF). In addition neither grain, core, cob or stover yield differed ($p > 0.05$) between treatments at the end of the long rains cropping season during the first year of the fallow (Fig. 3). During the establishment season of the *Sesbania* fallow, when maize and *Sesbania* were intercropped, there was also a loss in maize production. During the intercropping season, the loss in grain yield relative to continuous unfertilized maize was 16% in S6 and 27% in S18. The cumulative loss in grain yield during the four seasons (maize/*Sesbania* one season, *Sesbania* fallow three seasons) of the fallow period relative to continuous unfertilized maize was: S18, 87%; N18, 84%; S6, 35%; and N6, 23%. On the other hand, fertilizer application increased grain yield by 56% during the fallow period (Fig. 3A).

Productivity of the different rotation systems was established after four seasons. Lower maize yields were recorded in the short rainy season as compared with the long rainy season (Fig. 3). The residual total above-ground biomass of maize (cobs + stover) in the first growing season after the fallow appeared to be the highest ($F_{5, 15} = 33.44$, $p < 0.001$) at the *Sesbania* fallows (10.87 ± 0.94 t·ha^{-1} and 9.68 ± 0.99 t·ha^{-1}, respectively for S18 and S6) while it was similar for all other treatments (mean values ranged from 3.74 ± 0.58 t·ha^{-1} and 5.14 ± 0.66 t·ha^{-1}). In the first long rain season after the fallow, grain yield increased significantly ($F_{5, 15} = 57.93$, $p < 0.001$) relative to continuous unfertilized maize plots by 239% in the 18-month *Sesbania* fallow and 170% in the 6-month *Sesbania* fallow. Grain production was significantly higher on *Sesbania* fallows than in continuous unfertilized maize for two growing seasons (SR and LR) for the 18 months and for one growing season (LR) for the six months *Sesbania* fallow (Fig. 3A, B). In the second year after the fallow (1997), no statistically significantly difference was observed between treatments for maize grain yield during the long rain season. In contrast during the short rain cropping season, grain yield was similarly higher in the continuous maize with fertilizer and the S18 ($F_{5, 15} = 7.86$, $p = 0.001$) compared with the other treatments. In the third year after the fallow (1998) grain yield was higher ($F_{5, 15} = 20.57$, $p < 0.012$) in the continuous maize with fertilizer than other treatments. Cumulative maize grain yield for five seasons after the *Sesbania* fallow was 41% higher in S6 and 87% higher in S18 than in continuous unfertilized maize, which yielded 7.9 t·ha^{-1}. Cumulative maize grain yields in continuous maize were 56% higher for plot with fertilizer than without. One season of maize cropping after the fallow was required to recover the loss in grain production for the 6-month *Sesbania* fallow and two seasons for the 18-month fallow. Four seasons of continuous

maize cropping could not recover the maize grain lost after the natural fallows. The overall net grain yield due to the effect of the treatments relative to continuous unfertilized maize over the entire experiment was: N18, -5.1 t·ha^{-1}; N6, -1.2 t·ha^{-1}; S6, 1.0 t·ha^{-1}; S18, 1.5 t·ha^{-1}; MF, 7.9 t·ha^{-1}. These calculations presume that there was no interaction with climate variation during that period, since precipitation and temperature did not show marked inter-season variation during the main part of the growing seasons.

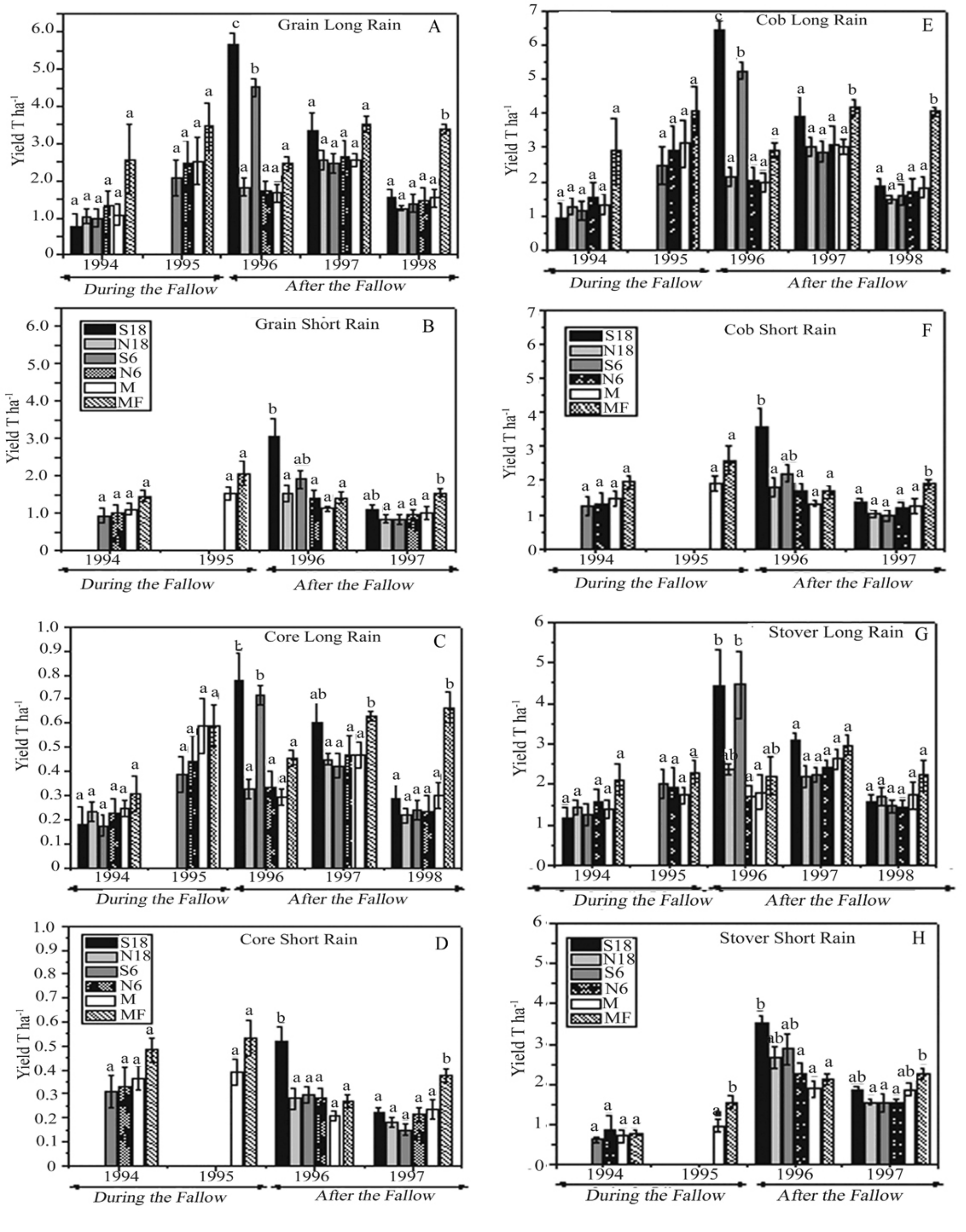

Fig. 3 Yield of maize grain (A, B), maize core (C, D), maize cob (E, F) and maize stover (G, H) during the fallow (kg·ha^{-1}) and the experimental period at Ebukanga, Vihiga district, western Kenya. Within the same year mean (±SE) with different letter are statistically different based on Tukey's test.

In the first long rain following the fallow period core, cob and stover productions were higher ($p < 0.05$) after the 18 months, 6 months *Sesbania* fallow than all other treatments. The residual benefit for *Sesbania* fallow lasted for two seasons for stover as

indicated by the higher yield in the long rain of 1997 following 18 months *Sesbania* fallow than other land uses systems ($F_{5, 15}$ = 2.62, p = 0.048) (Fig. 3G). When fertilizer was supplied (MF) a yield increase was observed for cob and core ($p < 0.001$) during the long rain of the last year of the experiment compared to the other treatments. Yield of stover, core and cob was generally high during the long rainy season as compared with the short rainy season. The residual effect of the *Sesbania* fallow lasted for one consecutive short rainy seasons for stover, cob and core following S18 treatment.

Striga hermonthica plant numbers

Striga hermonthica infestation at the onset of the fallow period was generally high (ranging from 227 000 ± 73 000 to 496 000 ± 158 000 shoot per ha in the long rainy season of 1994) although no significant difference was observed between the treatments (p = 0.529). After the first cropping season of the fallow period (in the short rainy season of 1994) *S. hermonthica* numbers were tremendously reduced in all treatments (Table 3). *S. hermonthica* plant populations decreased dramatically in continuous maize between the first season (mean = 428 × 10^3 ha^{-1}) and second season (mean = 61 × 10^3 ha^{-1}). In the first cropping season following the fallow period, *S. hermonthica* number was significantly ($F_{5, 15}$ = 13.09, $p < 0.001$) higher in the N18 as compared with the other treatments; *S. hermonthica* number was the lowest at S18. Compared with the plots that were continuously maize cropped (M), there was a temporary flush in the number of *S. hermonthica* plants in the first two seasons after the fallow on the plots that received natural weed fallow (N18) and in the second season on the 18 months *Sesbania* fallow (S18). Fertilizer decreased *S. hermonthica* plant populations by 42% over all seasons but the difference was less in the second four seasons (23%) than in the first four seasons (47%) compared with continuously maize cropping. In the long rain season of 1997, the number of *Striga* plants was significantly ($F_{5, 15}$ = 3.57, p = 0.025) lower on plots receiving continuous maize and fertilizer compare with the other treatments.

Table 3. Number of *Striga* plants (x 1000 ha^{-1}) during seven seasons (fallow period ended after SR95).

Growing season	S6	S18	N6	N18	M	MF
1994 LR	408±95a	496±158a	329±114a	414±63a	428±63a	227±73a
1994 SR	32±10ab	0±0a	36±14ab	0±0a	61±17b	41±18ab
1995 LR	18±8ab	0±0a	23±11ab	0±0a	39±9b	21±11ab
1995 SR	0±0a	0±0a	0±0a	0±0a	32±9b	8±2a
1996 LR	23±9a	10±4a	51±7a	139±25b	54±15a	51±10a
1996 SR	74±18a	169±76a	52±17a	123±31a	57±13a	54±11a
1997 LR	54±6b	41±12ab	30±3ab	32±4ab	39±9ab	14±5a
1997 SR	18±5a	12±2a	14±5a	10±3a	12±4a	5±3a

Data for the same year not marked with the same letter are significantly different. For notations see Table 1. Values are mean ± Standard Error.

Striga hermonthica seed bank

S. hermonthica seed density in the soil at the onset of the fallowing period was 155 ± 16 seeds per kg of soil. The majority of the *S. hermonthica* seed in all treatment plots was found in the upper 0–15 cm of the soil profile. The average total seed numbers found in all treatment plots at the two (0–15 cm and 15–30 cm) soil depths levels were not significantly ($p > 0.05$) different from each other in any of the seasons. There was a decline in seed density with depth at the end of both short (SR) and long (LR) rainy season for all treatments except for MF in the SR 1995 and SR 1996 and for M in the SR of 1996. Trends in *S. hermonthica* seed density at the soil depth of 15–30 cm were not significant and the overall mean population was 49 seeds kg^{-1}. However, there was a decreasing trend in the top soil (0–15 cm) throughout the duration of the experiment in the continuous maize treatments and an increasing tendency in seed populations after the fallow treatments, most notably in S18 and N18 (Table 4).

Table 4. Number of *Striga hermonthica* seeds (seeds kg^{-1} soil), (Standard Error) in seed numbers following different treatments

Growing Season	Soil depth (cm)	S6	S18	N6	N18	M	MF
1993 SR	0-15	179±40a	149±41a	116±15a	150±41a	174±64a	164±48a
1994 LR	0-15	148±34a	134±48a	158±50a	181±43a	138±37a	82±31a
1994 SR	0-15	115±17a	65±5a	130±62a	106±11a	151±68a	59±10a
1995 LR	0-15	152±51a	40±7a	90±24a	76±9a	84±25a	100±35a
1995 LR	15-30	76±12a	26±11a	38±14a	64±30a	39±14a	45±18a
1995 SR	0-15	45±19a	28±6a	50±18a	38±16a	76±19a	26±9a
1995 SR	15-30	39±8a	41±4a	38±12a	36±7a	46±5a	34±11a
1996 LR	0-15	48±24a	63±16a	34±7a	146±80a	50±20a	94±69a
1996 LR	15-30	41±6a	16±4a	31±15a	58±17a	38±2a	26±6a
1996 SR	0-15	55±21a	111±59a	99±34a	125±26a	57±7a	37±10a
1996 SR	15-30	64±16a	67±29a	61±19a	119±61a	70±21a	57±26a

Data for the same year not marked with the same letter are significantly different. For notations see Table 1.

Discussion

Continuous maize monocropping was the least productive option in all seasons, although non-significant which is in agreement with previous yield data from the same area (Jama et al. 1998a) and corresponds to the low yields typical of subsistence agriculture in the tropics (Stahl et al. 2002). Lower yield in the short rainy season may be explained by the lower rainfall and higher incidence of pests and diseases in the short rainy season (Jama et al. 1998b). The lower yield in the short rainy season of 1997 despite the generally higher rainfall in this season can be attributed to erratic distribution of the rains which is reported to result in severe crop stress (van Lauwe et al. 2002).

Improved fallows, as compared to continuous maize without fertilizer or natural grass fallows, increased grain, stover, cob and core yield of post-fallow maize. The residual benefit of fallow rotation using *Sesbania* lasted for one to four cropping seasons which is in agreement with previous results (Kwesiga et al. 1999; Stahl et al. 2002; Ndufa et al. 2009). The beneficial residual effect on maize yield following *Sesbania* can be attributed to a rapid supply of plant available N from decomposing fallow

biomass. The improved fallow system may have improved water availability to the maize crop by reducing runoff and increasing water infiltration (Nyamadzawo 2008) in the furrow during the fallowing period. In addition *Sesbania* may have contributed to weed suppression and therefore increased nutrient availability for the maize. Fewer weeds were observed in the maize-*Sesbania* plots than in the sole maize plots (pers. observ.). Consequently, the *Sesbania* system could offer an attractive option for soil improvement, especially on the fields of resource-poor farmers (Kwesiga et al. 1999). In addition it will provide fuelwood and fodder benefit. The reduction of *S. hermonthica* emergence in S18 in the season immediately after fallow clearance may have contributed to the increased maize yield relative to continuous unfertilized maize. On the other hand the increased fertility after the fallow could have allowed maize to more effectively outcompete *S. hermonthica*. The increased maize yield in most of the post fallow seasons with the fertilization treatment (P and N) indicates N deficiency and confirms the merit of N fertilization of N-deficient soils similar to our experimental site.

The results indicated that at the end of the cropping season, highest numbers of *S. hermonthica* seeds were found in the 0–15 cm soil profile which corresponds to the plough layer of the soil. This finding conforms with detailed information about the spatial seed distribution from a number of naturally infested farm fields in Western Kenya (van Delft et al. 1997) which indicated that *S. hermonthica* seeds are found to a depth of approximately 10–15 cm. Below this level few seed was found up to 30 cm in all treatments plots which could be explained by seed migration through soil pores and pathways caused by decomposition of plants roots (Smith and Webb 1996). The high density of *S. hermonthica* seed in the upper layer where the first roots of the crop plants are usually located (van Delft et al. 2000) could result in a relatively early and highly infested root system of the maize, which in turn might explain the losses in yield observed. Since *S. hermonthica* is a root parasite, the interaction between host and parasite first occurs at the level of parasite seed germination and attachment. *S. hermonthica* plant populations decreased dramatically in continuous maize cropping, presumably in response to good weed management compared with farmer management before the experiment.

The lower number of emerged *S. hermonthica* shoots in maize intercropped with legumes might be attributed to the shading effect of the legumes or a change in humidity and temperature conditions due to their dense canopy. Fodder legumes can reduce *S. hermonthica* infestation as trap crops or due to suppression of emerged *S. hermonthica*. They can form a valuable part of an integrated *S. hermonthica* control strategy. In the continuous maize treatment, a substantial proportion of the newly produced *S. hermonthica* seeds may have not survived in the topsoil during the subsequent dry season until the next cropping. This could explain a drastic decrease in *S. hermonthica* seed viability or additional factors could be responsible for reducing the seed bank annually predominantly acting near the soil surface such as consumption of seed by insects and earthworms, suicidal germination, stimulation by root exudates, other organic compound or micro-organisms and infestation by fungi (van Delft et al. 2000; Oswald and Ransom 2001). In the treatment without weeding in N18, an increase of the seedbank occurred which is similar to an earlier finding by (Ransom and Odhiambo 1994). The relative increase in *S. hermonthica* following S18 in our study conflicts with the pattern of reduction of *S. hermonthica* infection in maize following planted fallows, which is believed to occur due to increased mineral N in the topsoil and/or depletion of *S. hermonthica* seed during the fallow phase (Gacheru and Rao 2005). This observed suppression may in fact have also been the effect of previous years without a host and due to a persistent seed bank found under both laboratory and field conditions (Samake et al. 2006). Fertilizer decreased *S. hermonthica* plant populations which is consistent with other studies that have shown that nitrogen fertilizer decreases *S. hermonthica* populations (Odhiambo 1998).

Conclusion

The study provides evidence that on a N-deficient site infested with *S hermonthica*, natural weedy fallows of 6-month and 18-month duration had no residual effect on maize grain yield. Improved *Sesbania* fallows had transient effects on residual maize yield, the size and duration of which was approximately proportional to the length of the fallow. There were small positive net yield effects of *Sesbania* fallows amounting to about 1 to 1.5 $Mg{\cdot}ha^{-1}$ over the duration of the experiment, compared with 7.7 $Mg{\cdot}ha^{-1}$ with fertilizer addition in continuous maize. Longer-term experiments are required to test whether *Sesbania* and other leguminous fallows can gradually build up larger benefits over the long-term in addition to the short-term transient yield effects observed in this experiment. *S. hermonthica* populations were strongly reduced by the generally improved weed management during the experiment and to fertilizer use in the continuous maize treatment. On the other hand, weed and natural fallow tended to increase *S. hermonthica* plant populations, and *Sesbania* fallow also increased *S. hermonthica* seed populations in the soil. Longer-term studies are required to confirm whether good weed management can off-set the effects of *Sesbania* fallows on increased *S. hermonthica*.

Acknowledgment

We thank Paul Smithson and the ICRAF soil laboratory staff in Machakos and Maseno for soil and plant analysis services. We thank A. Albrektson, L. Eliasson and P. Savadogo for manuscript reading. We gratefully acknowledge financial support from the Swedish International Development Cooperation Agency (Sida).

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